Understanding climate change impacts on ozone concentrations in Delaware

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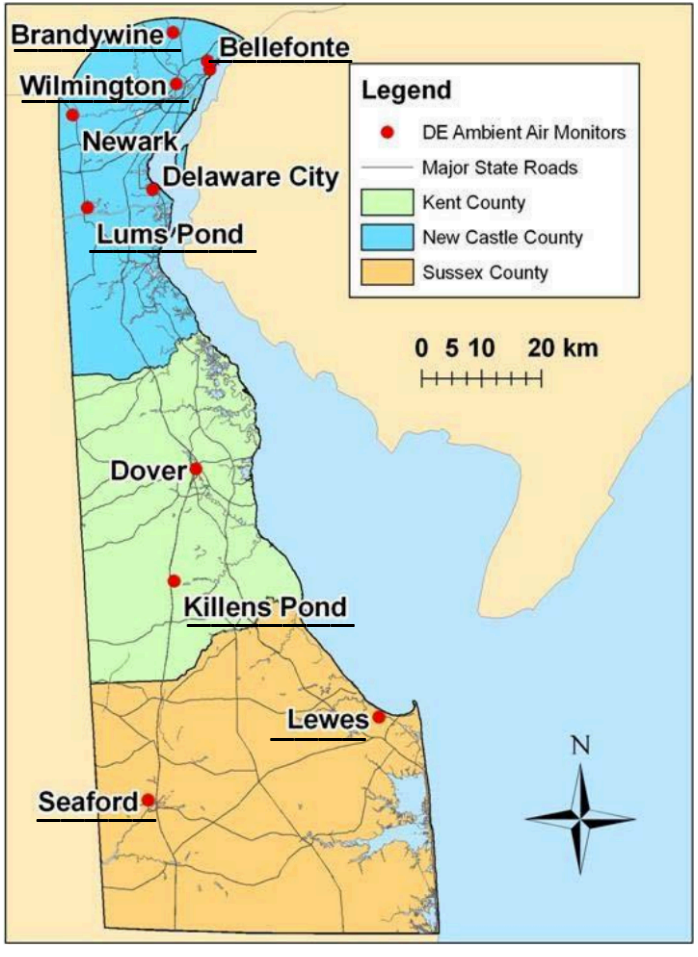
How do we estimate the expected changes in frequency of high-ozone episodes in Delaware?

1. Link synoptic types and high-ozone (HO) days based on observations;
2. Use selected climate models to calculate past and future frequency of HO synoptic types;
3. Focus on two future scenarios:
   - Business-as-usual;
   - Moderately optimistic (~2015 Paris agreement).

Ozone stations in Delaware



- 10 monitoring stations, 7 for ozone;
- Records dating back to 1981;
- Several stations were suspended or relocated.

	SO_2	NO_2	CO	O_3	PM_{10}	$PM_{2.5}$	Lead	Wind
Brandywine				x				x
Bellefonte	x			x		x		
Wilmington	x	x	x	x	x	x	x	x
Newark						x		
DE City	x		x					x
Lums Pond	x			x		x		x
Dover						x		
Killens Pond				x		x		x
Seaford				x		x		x
Lewes	x			x				x

Use AQI to identify past high-ozone (HO) days

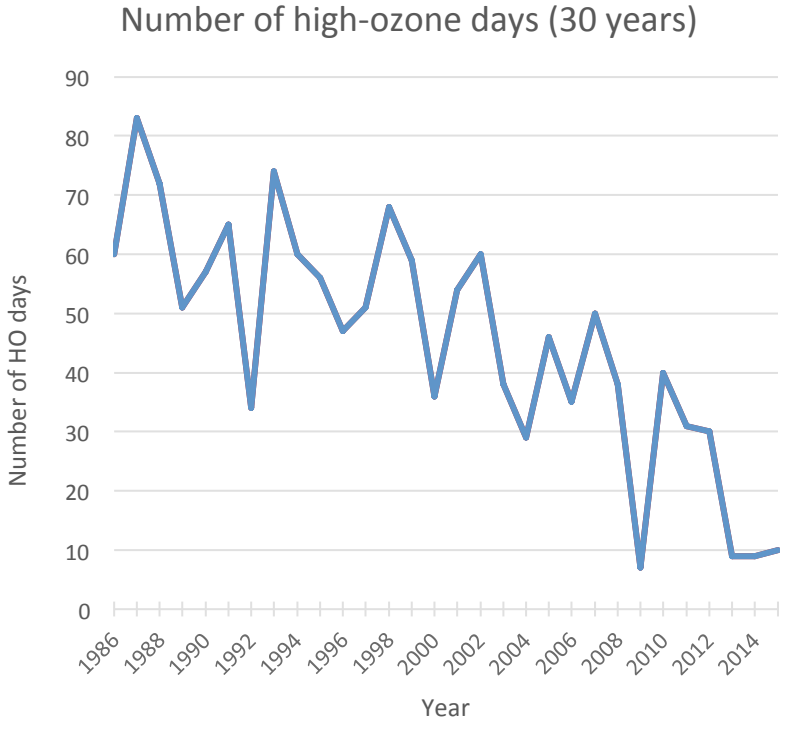
- Classify observations according to Air Quality Index (AQI) scale for O_3;
- If at least one station exceeds the AQI of 100 (O_3 > 70 ppb, 8-hr avg), classify as a "high-ozone day";
- Example: 4-8 August 2001.

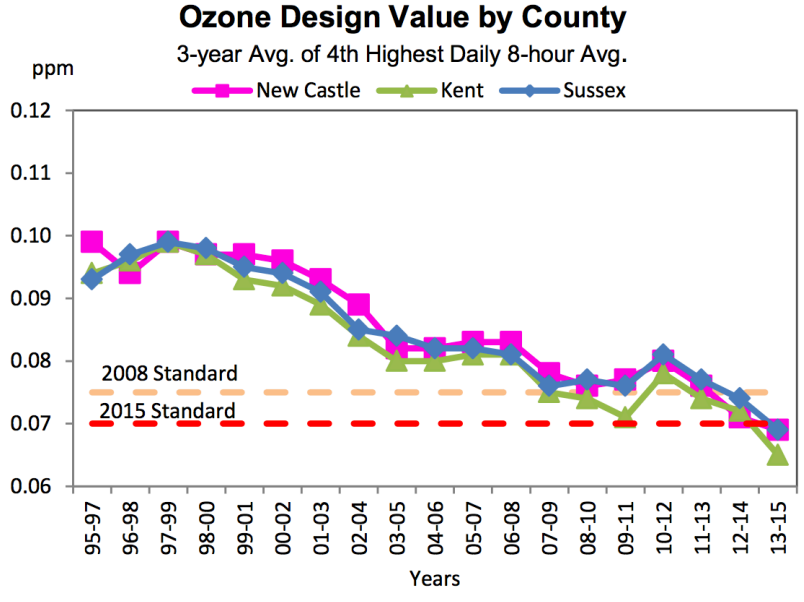
AQI Category	Index Value	8-hr Ozone (ppb)
Good	0 – 50	0 – 54
Moderate	51 – 100	55 – 70
Unhealthy for Sensitive Groups	101 – 150	71 – 85
Unhealthy	151 – 200	86 – 105
Very Unhealthy	201 – 300	106 – 200
Hazardous	301 – 500	201 – SHL*

*SHL = Significant Harm Level, 600 ppb, 2 hour avg

	# Stat	High Avg	Killens	Lums	B'wine	B'fonte	Seaford	Lewes	Syn Type
4-Aug-01	0	0.000	0.050	0.051	0.061	0.049	0.046	0.044	3034
5-Aug-01	2	0.085	0.054	0.069	0.089	0.080	0.059	0.051	3032
6-Aug-01	2	0.083	0.059	0.069	0.089	0.077	0.064	0.066	3034
7-Aug-01	6	0.101	0.105	0.097	0.102	0.098	0.106	0.099	3034
8-Aug-01	6	0.094	0.097	0.098	0.095	0.090	0.096	0.086	3034

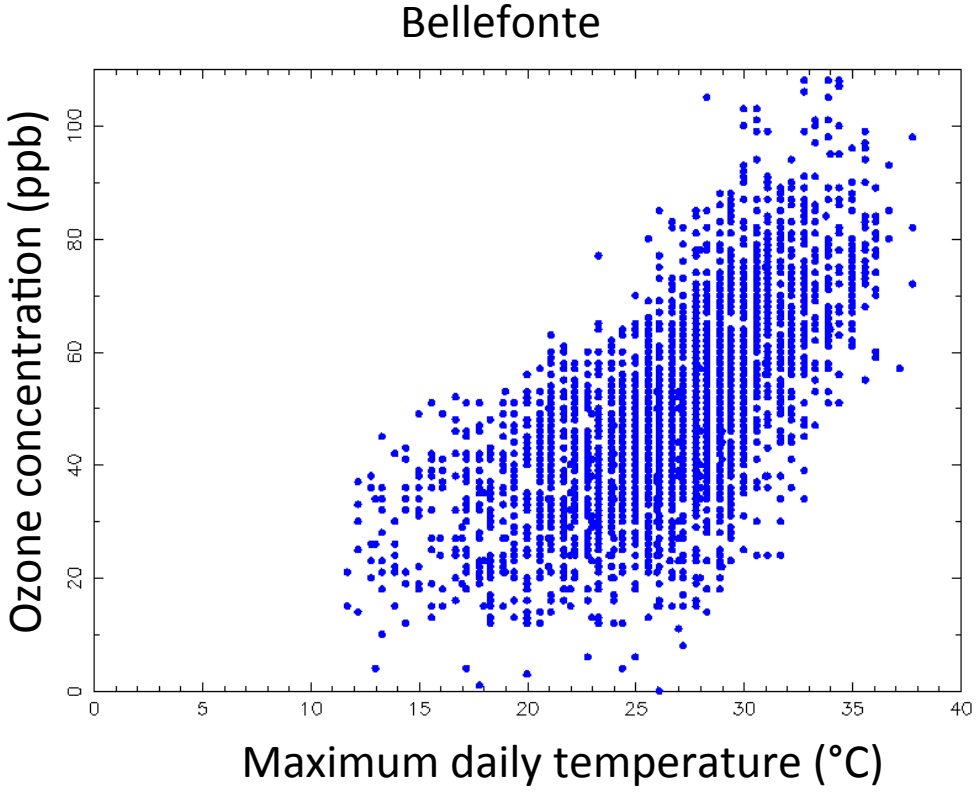
Regulation success: Ozone decreasing in frequency and intensity





http://www.dnrec.delaware.gov/Air/Pages/DAQ-Annual-Reports.aspx

Concern about global warming: Ozone increases with temperature!



Synoptic typing

- Principal Component Analysis (PCA) of meteorological observations to evaluate common features of various synoptic weather conditions:
  - Temperature;
  - Dew point temperature;
  - Pressure;
  - Cloud cover;
  - Wind speed and direction.
- Data from Dan Leathers and his group in Geography:
  - Available from 1948 onward;
  - Several surface locations – we use Philadelphia.

Winter:
1004: Weak Carolinas Low
1005: Weak unclosed Upper GL Low
1006: Labrador Low
1008: Cold Front Passage
1009: Strong Mid-West High
1010: Weak GL Low, Southwest Flow
1011: New England Low
1016: Southwest Flow
1019: Strong New England Coastal Low
1020: Strong Labrador Low
1031: GL Low
1032: Mid-Atlantic Coastal Low
1033: Off-shore Low w/ Mid-West High
1034: New England High
1035: Mid-Atlantic High

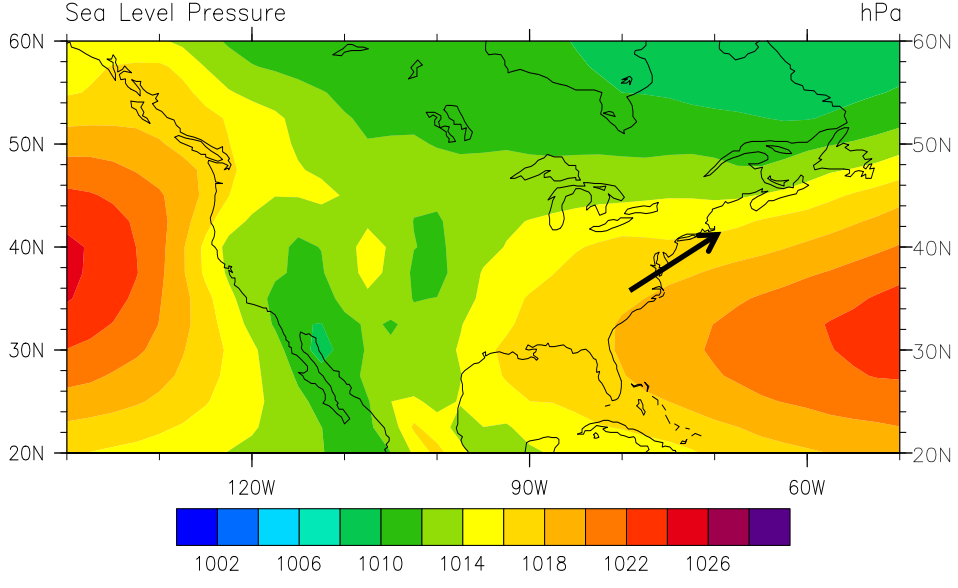
Spring:
2006: Mid-West High
2012: Mid-Atlantic Low
2017: Carolinas High
2018: Weak Pattern
2020: Coastal Low
2031: Upper New England Coastal Low
2032: Mid-West/GL Low
2033: Overhead High
2034: Coastal High, SSW-flow
2035: Northerly Flow
2036: Weak South Flow
2037: Southwest Flow

Summer:
3006: Hudson's Bay Low, Frontal Activity
3010: Weak Southwest Flow
3013: New England High
3020: North-Northwest Flow
3031: Off-shore High
3032: Weak Pattern
3033: New England Low
3034: Southwest Flow
3035: Overhead High

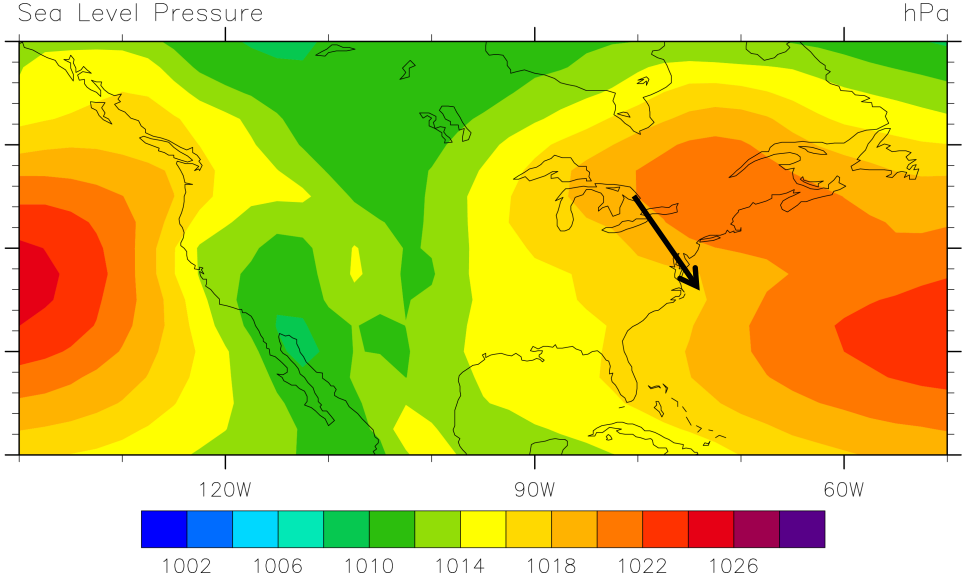
Autumn:
4003: Southwest Flow
4004: Weak Pattern
4006: Western PA High, NE-flow
4009: Cold Front Passage
4010: New England High
4012: Carolinas High, E-flow
4031: New England Low
4032: GL Low
4033: Overhead High
4034: Northwest Flow
4035: Mid-Atlantic Coastal Low

Southwest flow associated with HO days

Synoptic Type 3034 (HO)

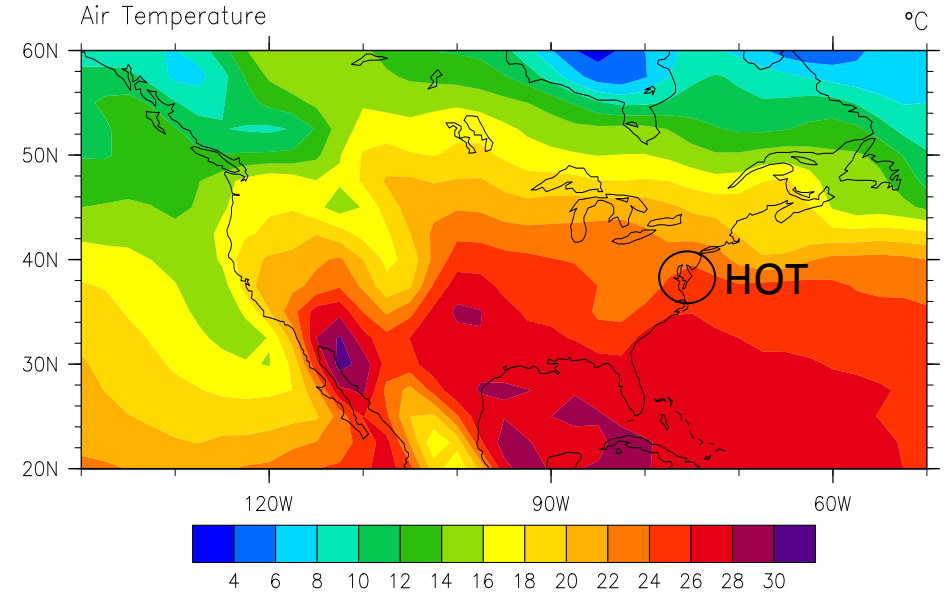


Synoptic Type 3013 (<u>not</u> HO)

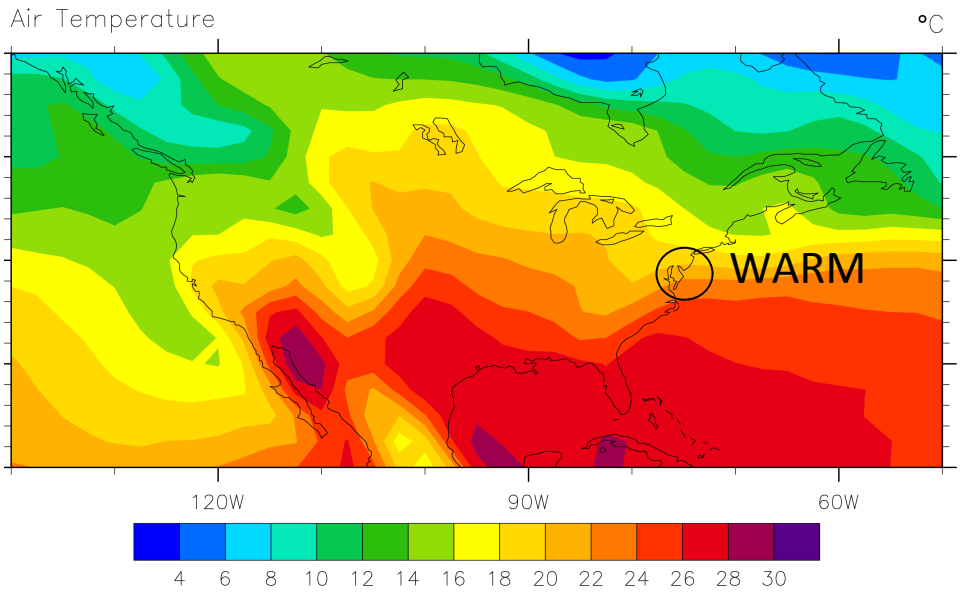


High temperatures associated with HO days

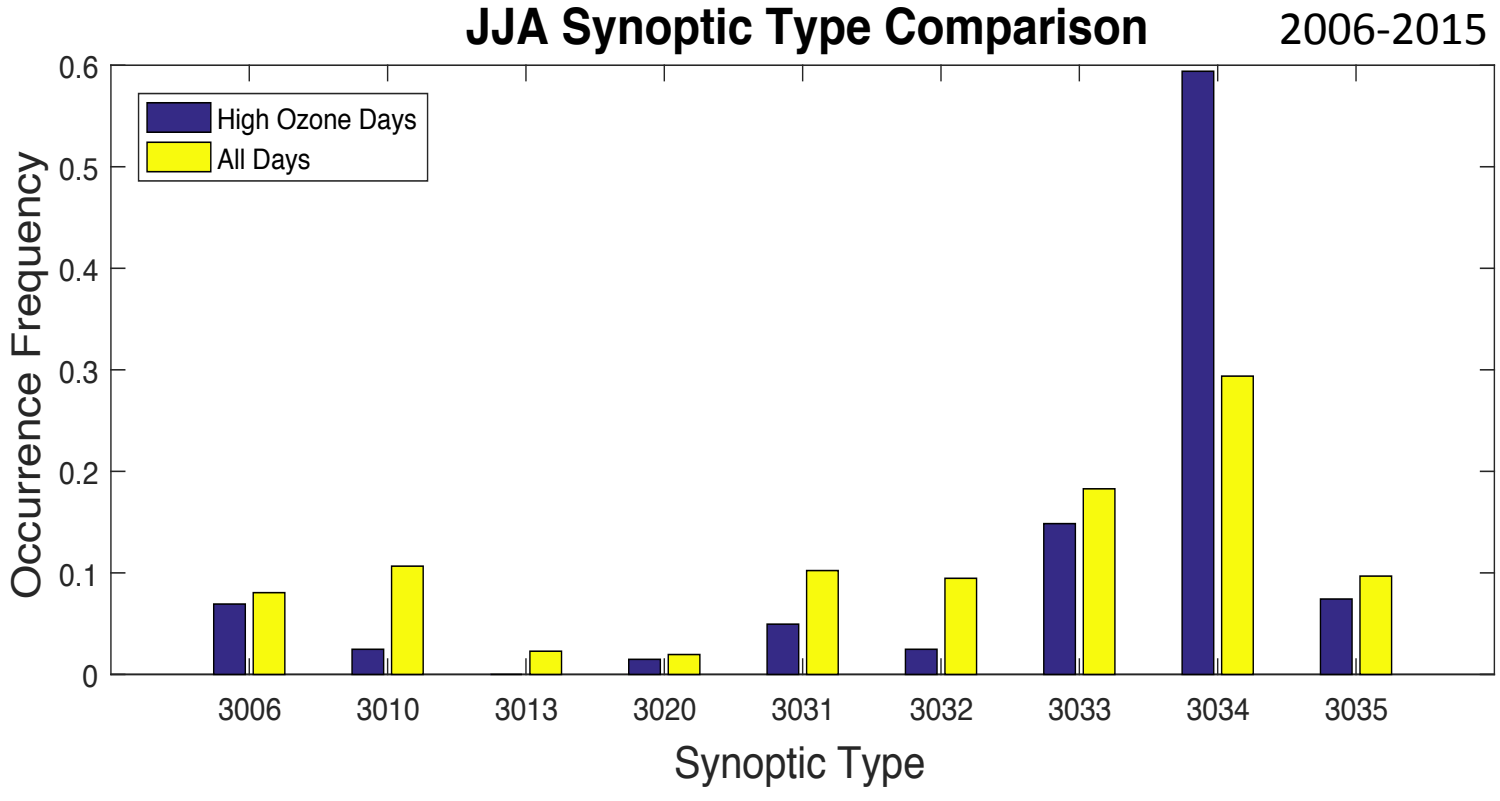
Synoptic Type 3034 (HO)



Synoptic Type 3013 (<u>not</u> HO)

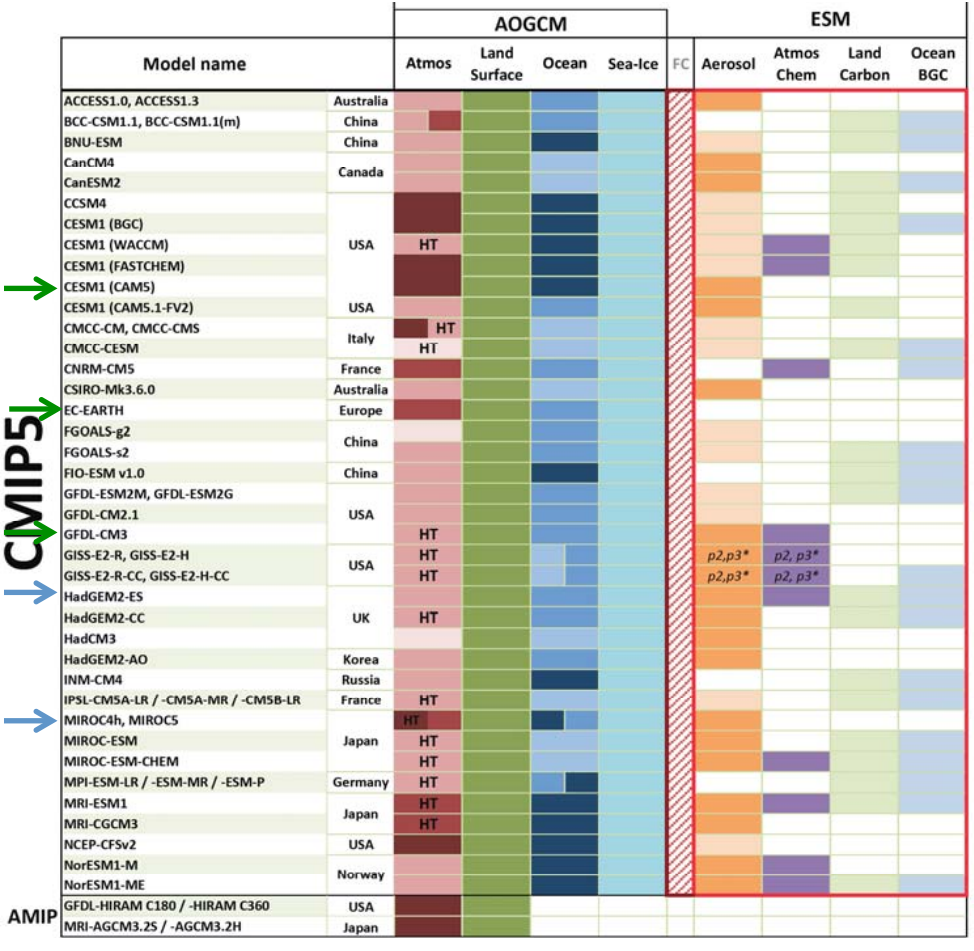


Type 3034 dominant during HO days

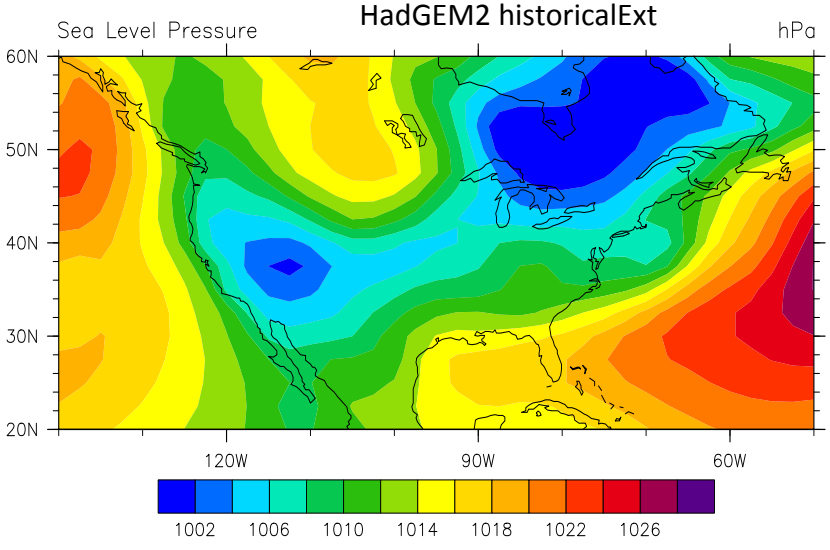


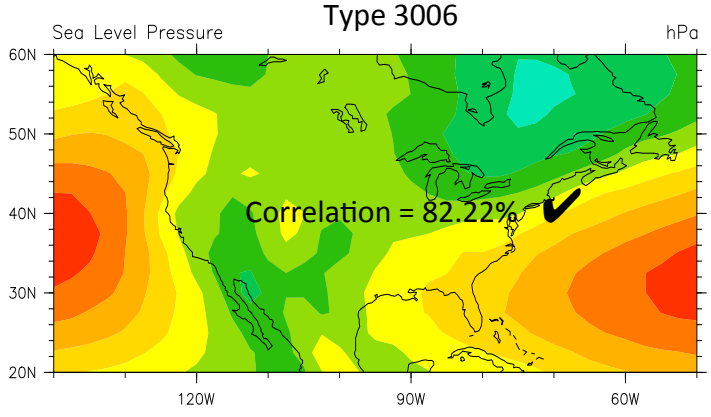
Climate models are computer predictions

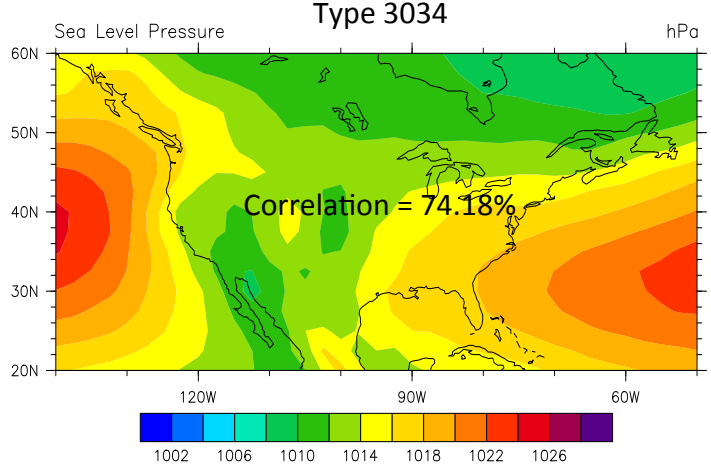
- Many climate models with many variants are run by many groups worldwide (CMIP5 collection);
- Here we use HadGEM2 and MIROC5 for the historical period and a future business-as-usual scenario (RCP8.5);
- Later we will add GFDL, ECHAM, CESM;
- Using multiple models adds confidence in results and allows probabilistic assessments;
- We don't expect day-to-day correspondence between models and observations or between the models;
- However, we do expect the model climate to look like the real climate <u>on average.</u>



Use spatial pattern correlation to identify synoptic type

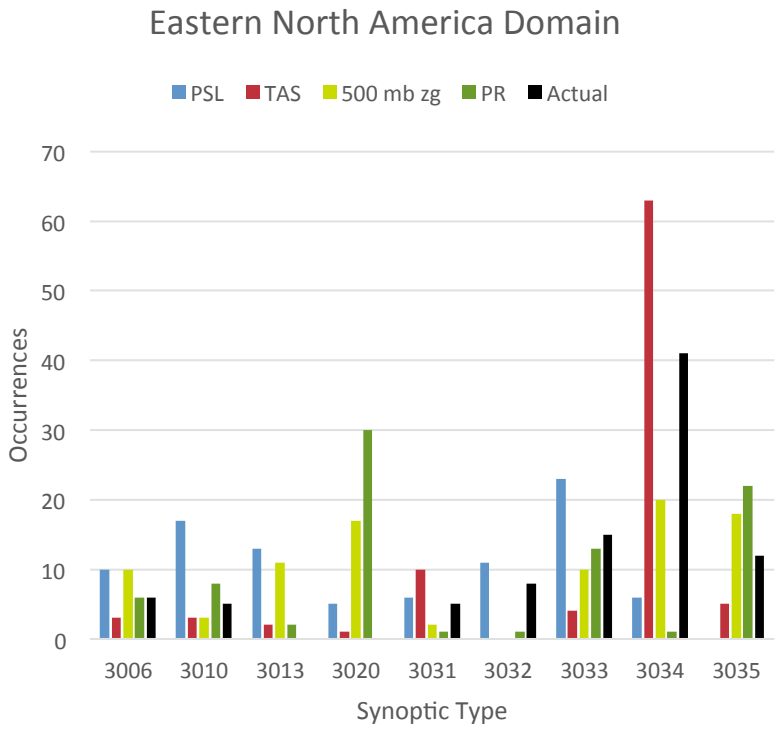






Methodology to identify HO days

- Use Eastern part of the North America domain to be more DE-specific;
- No single variable gives exact distribution as observations;
- To classify a day as HO, these conditions must be satisfied:
  - Be classified as synoptic type 3034, 3006, 3010, or 3033 using SLP;
  - Mean daily temperature for DE > 25.5 °C;
  - No precipitation for DE (PR < 1.0 mm/day).
- These conditions were based on last decade.



Historical results

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Historical and projected results

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Conclusions

- O_3 regulation in DE has been successful at reducing O_3 despite underlying rising temperatures due to global warming;
- Method was developed to link HO days and synoptic types for climate models;
- Number of HO days is expected to increase in the absence of changes in regulation;
- Future work:
  - Look at more models (GFDL, ECHAM, CESM);
  - Is high O_3 getting higher, not only more frequent?